1 427 826

PATENT SPECIFICATION

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(54) METHOD OF PRODUCING AN OPTICAL TRANSMISSION LINE

(71) We, SUMITOMO ELECTRIC INDUSTRIES, LTD., a Japanese Company, of No. 15, 5-Chome, Kitahama, Higashi-ku, Osaka, Japan, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method of producing an effective optical transmission line for use in an optical communication system.

The method of the invention is applicable to the production of an optical transmission line comprising a triple-layered construction comprising a core (e.g. of high purity fused silica) having an extremely low optical transmission loss surrounded by a thin cylindrical layer having a refractive index several per cent higher than that of said core material, said thin layer being further surrounded by a cladding layer having the same refractive index as that of the core.

The theory for the optical energy transmission through a line of this type of construction is disclosed in the technical paper No. 852 "Transmission Properties of the Optical Fibre having thin Cylindrical Layer of a Higher Refractive Index than that of the Fibre Material" of the General Conference 1972 and the technical paper No. 995 "The Transmission Properties of HE_{11} mode in the Optical Fibre which has a Cylindrical Thin Layer of a Higher Refractive Index than that of the Fibre Material" of the General Conference 1973, of the Institute of Electronics and Communication Engineers of Japan.

Optical transmission lines comprising double-layered constructions of cores and cladding layers coated thereon and the processes for their production have been widely developed in the prior art, for example as disclosed in U.S. Patent No. 3,659,915. An optical transmission line having a triple-layered construction is also disclosed, for example, in the Japanese Patent Application laid open to inspection as No. 31961/1973.

The present invention provides a method of producing an optical transmission line, comprising disposing a rod of a transparent medium coaxially within a hollow cylinder of a transparent medium having the same refractive index as said first medium and heating and drawing said rod and cylinder to reduce their diameters and form therefrom an integral fibre, said method including, before said heating and drawing step, the step of forming, on the external surface of said rod or on the internal surface of said cylinder, a transparent layer having a refractive index higher than that of the medium of the rod or the cylinder.

This invention also provides a method of producing an optical transmission line comprising a very thin fibrous body of a medium with optical transmission loss, that is, having a high dielectric loss tangent along the axis of said rod.

The invention is illustrated by way of example in the accompanying drawings, in which:

Figure 1 is a cross-section of an optical transmission line produced by the method according to this invention;

Figure 2 is a longitudinal section of the optical transmission line shown in Figure 1;

Figure 3 is a chart showing the refractive index of the optical transmission line medium in relation to the cross-section shown in Figure 1;

Figure 4 is a section of an optical transmission line for illustrating the method according to this invention for producing the optical transmission line;

Figure 5 is a view illustrating the method according to this invention for producing the optical transmission line;

Figure 6 is a cross-section of another optical transmission line produced according to the method of this invention;

Figure 7 is a longitudinal section of the optical transmission line shown in Figure 6;

Figure 8 is a chart showing the refractive index of the optical transmission line

medium in relation to the cross-section shown in Figure 6;

Figures 9 and 10 are further views illustrating the method according to this invention for producing the optical transmission line; and

Figures 11 and 12 are respectively views illustrating another embodiment of the method according to this invention for producing the optical transmission line shown in Figure 6.

Referring to Figures 1—3, Figures 1 and 2 show a known construction of an optical transmission line, in which 1 and 3 are cylindrical media transparent to light and 2 is a cylindrical medium interposed between the cylinders 1 and 3 and also transparent to light but having a refractive index which is several per cent higher than that of the media 1 and 3. The relative refractive indices of the media 1, 2 and 3 are shown in Figure 3. The thickness of the layer 2 is a fraction of several times to several tens of times the wavelength of light to be transmitted by the transmission line.

The fundamental mode in the transmission line as shown in Figures 1 and 2 is HE_{11} mode and the modes TE_{01}, HE_{21}, . . . can successively be transmitted by increasing the transmission frequency. It has been theoretically proved that most of the optical energy is concentrated in the layer 2 in such an optical transmission line. By appropriately selecting the dimensions and electrical properties of such an optical transmission line, it can be made possible to transmit only the two modes HE_{11} and TE_{01}. A typical example for such a transmission line includes a medium 3 of 13μ diameter and a thin layer 2 of 0.13μ thickness, the refractive index of the media 1 and 3 being 1.50 and that of the thin layer 2 being 1.52 for light having the wavelength: $\lambda=1\mu$. The outer diameter of the optical transmission line can optionally be determined for example from about 50μ to about 200μ depending on requirements.

This invention relates to a method of producing an optical transmission line as shown in Figures 1 and 2. A method of producing an optical transmission line according to this invention will be described below with reference to Figure 4, wherein the reference numbers 1, 2 and 3 indicate the same parts shown in Figure 1. In Figure 4, 11 denotes a hollow cylinder consisting of material such as optical glass, high purity fused silica or the like. 12 represents a deposited layer having a refractive index several per cent higher than that of said cylinder and deposited on the inner surface of said cylinder in a uniform thickness. 13 is a cylindrical rod of the same material as that of said cylinder and concentrically disposed with respect to the cylinder, 15 shows a high temperature furnace and 16 shows a fibrous spun body.

According to the method of this invention for producing an optical transmission line, the inner surface of the cylinder 11 should initially be finished very smoothly by such means as mechanical polishing, Laser finishing, sapphire polishing, hydrofluoric acid polishing, flame polishing or the like. Then, a thin deposition layer 12 is formed on the inner surface of the cylinder 11. The material for the deposition layer 12 is a medium with less optical transmission loss and having a refractive index 0.1—10% higher than that of said cylinder 11. Accordingly, when fused silica (refractive index 1.4584) is employed for the cylindrical medium 11, the deposition layer 12 may consist of material having a refractive index of 1.47. The material for the deposition layer may include, but is not limited to, optical glass or doped fused silica containing one or more metallic oxides such as titanium oxide, tantalum oxide, tin oxide, niobium oxide, zirconium oxide, aluminium oxide and oxides of alkaline and alkali earth metals in order to produce the desired refractive index.

The method of applying the deposition layer 12 on the inner surface of the cylinder 11 may include, for example, radio frequency sputtering, deposition by flame fusion (e.g. by deposition in fine powder form followed by sintering to effect vitrification), chemical vapour deposition, deposition of glass frit, and immersion of the inner surface of the cylinder in a fluid which will perform an ion exchange with the material of the cylinder 11. In one preferred process the layer is formed in a vitreous state in a single step.

As an example, a method is to be described which comprises depositing on the inner surface of the cylinder 11, a fused silica layer containing titanium oxide by flame fusion. A vapour mixture of silicon tetrachloride and titanium tetrachloride in a required ratio is mixed with gaseous oxygen and passed through an oxyhydrogen flame to fuse the same into finely divided particles consisting of the required silicon dioxide and titanium dioxide. The finely divided particles are introduced in the cylinder 11 to deposit on the inside wall thereof. The reaction temperature employed is about 1200°C. Then, by heating the cylinder 11 and deposited finely divided particles approximately to 1600°C in an oxygen atmosphere, the particles are sintered and a thin deposition layer 12 of fused silica containing titanium is thus formed on the inside wall of the cylinder 11.

The foregoing example discloses two steps in which finely divided particles consisting of a uniform mixture of silicon

dioxide and titanium dioxide are deposited on the inner surface of the cylinder 11 and then sintered. Alternatively, the temperature of the oxyhydrogen flame may be kept higher and a glassy deposition layer consisting of a mixture of silicon dioxide and titanium dioxide can thus be formed on the inner surface of the cylinder 11 in a single step.

It is thus possible to form, on the inner surface of the cylinder 11, a deposition layer 12 having a refractive index several per cent higher than that of the cylinder 11 according to the procedure described above. A cylindrical rod 13 is then inserted into the interior of the cylinder 11 and coaxially supported there. The material of said round rod 13 is the same as that of the cylinder 11. The outer surface of the cylindrical rod is smoothly finished in the same way as described above for the inner surface of said cylinder. Then, the round rod 13 and the cylinder 11 are heated by the surrounding furnace 15 to such an extent that they acquire a viscosity sufficiently low for drawing into a filamentary shape, whereby the materials of the cylinder 11, the deposition layer 12 and the round rod 13 are softened and melt and flow downwards through the furnace at constant speeds respectively. The cross-sections at the lower ends of the cylinder 11, the deposition layer 12, and the round rod 13 are gradually decreased until the deposition layer 12 contacts the outside wall of the cylindrical rod 13 and then are further reduced in diameter to form a fibre having a cross-section as shown in Figure 1. This procedure is desirably performed in an oxygen atmosphere. The drawn products may be heated again and the drawn diameter thereof further reduced to a desired dimension, if necessary. The products thus obtained may be subjected to further heat treatment, as required, for example, for improving the optical transmission characteristics of the deposition layer 12. In the case of a deposition layer 12 the material of which is fused silica containing titanium oxide, for example, it is desirable to apply heat treatment as the temperature of 500°C—1000°C for more than 30 minutes.

Now, another embodiment of this invention will be described.

In Figure 5, the same reference numbers as used to denote the same parts as the corresponding numbers in Figure 4, reference number 12 representing a deposition layer formed on the outside wall of the cylindrical rod 13 and the method of forming the deposition layer 12 being the same as in Figure 4.

In the process shown in Figure 5, a cylindrical rod 13 comprising on the outside wall thereof a deposition layer 12 having a refractive index several per cent higher than that of said round rod 13 is disposed coaxially within a cylinder 11 of the same material as that of the cylindrical rod 13, and the lower ends of the cylindrical rod and cylinder are heated at a high temperature within the furnace 15 and are softened and then drawn to a desired diameter.

The embodiment shown in Figures 6, 7 and 8 represents still another type of optical transmission line, and the reference numbers in Figures 6 and 7 indicate the same portions indicated by corresponding numbers in Figure 1, 4 representing a very thin material provided at the centre of the medium 3 and having a higher dielectric loss tangent than the medium 3.

The optical transmission line shown in Figures 6 and 7 comprises optically transparent media 1 and 3, a thin cylindrical layer 2 of optically transparent medium inserted therebetween, and the central lossy material 4 provided at the centre of the medium 3 and having an extremely small diameter as compared with that of the thin layer 2. The thin layer 2 has a refractive index several per cent higher than that of the media 1 and 3 and a thickness of a fraction of several times to several tens of times the wavelength to be transmitted. In such a transmission line, uni-mode transmission, only for mode TE_{01}, is possible by appropriately selecting the dimensions and electromagnetic properties of the line.

One example of such an optical transmission line comprises media 1 and 3 having a refractive index of 1.50, a thin layer 2 having a refractive index of 1.52, a thickness of 0.15μ and a diameter of 13μ and a lossy core 4 having a diameter of 0.2μ.

Figures 9 and 10 illustrate the method for producing an optical transmission line as shown in Figure 6. In Figure 9, a first cylinder 33 of a transparent medium is shown which is made of material with an extremely low optical transmission loss, such as optical glass or high purity fused silica. The inner and the outer surfaces of the cylinder 33 should be polished by means similar to those described with respect to Figure 4. A deposition layer 34, with higher optical transmission loss, to form the central lossy material 4, is formed on the inner surface of the cylinder 33 and a thin deposition layer 32 having a refractive index greater than that of the cylinder 33 by several per cent is formed on the outer surface of the cylinder 33. Further, the physical properties of the material of layer 34 are desired to be similar to those of the material of cylinder 33. The material includes, for example, conventional glass material with relatively high optical

absorption for the transmission wavelength, fused silica containing small amounts of transition metal elements and the like. Methods of forming the deposition layer 34 include, for example, radio frequency sputtering, deposition by flame fusion, chemical vapour deposition, deposition of glass frit layer, vacuum deposition and immersion of the inner surface of the tube in fluid which will perform an ion exchange with the material of cylinder 33.

The method for forming the deposition layer 34 having optical transmission loss on the inner surface of the cylinder 33 shown in Figure 9 is just the same as that for forming the deposition layer 12 on the inner surface of the cylinder 11 shown in Figure 4 and the method for forming the highly refractive deposition layer 32 on the outer surface of the cylinder 33 is just the same as that for forming the deposition layer 12 on the outer surface of the round rod 13 shown in Figure 5.

As shown in Figure 9, the cylindrical materials 34, 33 and 32 thus formed are vertically arranged in the furnace 15 and heated until the lower ends thereof are softened and flow downward. The lower ends of said cylindrical materials 34, 33 and 32 flow downward at a constant velocity with the diameters thereof gradually decreasing, the central bore within the deposition layer 34 with optical transmission loss is closed and they are reduced to desired diameters and, thereafter, cooled and solidified.

In this way, a rod is formed comprising a triple-layered rod body including a lossy core 24 integrated with a deposition layer with optical transmission loss, a cylinder 23 surrounding the outer periphery of said core, and a highly refractive deposition layer 22 further surrounding the outer periphery of said cylinder 23.

The rod comprising portions 24, 23 and 22 thus formed and a second cylinder 31 surrounding them are disposed co-axially and inserted into the furnace 15. Then, the lower ends of said rod and the cylinder 31 are melted so that they flow downward, and are drawn into the diameters reduced to the desired extent in the same way as shown in Figure 4.

A still further embodiment of an optical transmission line according to this invention having the construction shown in Figures 6 and 7 will be described referring to Figures 11 and 12.

In Figure 11, a first cylinder 33 of transparent medium is shown which is formed from material with extremely low optical transmission loss, for example, optical glass, highly pure fused silica, or the like. The inner and the outer surfaces of the cylinder 33 should be finished very smoothly and they are polished in the same way as described in the case of the cylinder 33 shown in Figure 9. Then, on the inner surface of the cylinder 33, a thin deposition layer 34 having optical transmission loss is formed. The method is the same as described in the case of the embodiment shown in Figure 9.

The lower end of the double-layered cylinder 33 and 34 thus formed is heated in the furnace 15, softened to melt, and the bore within the deposition layer 34 with high optical transmission loss is closed as the cylinder is drawn to a diameter reduced to a desired extent and is then cooled and solidified thereby forming a double-layered rod portion 24, 23 as shown in Figure 12. The double-layered rod portion 24, 23 thus formed and a second cylinder 31 having a layer 22 of high refractive index obtained in a similar way to the layer 12 as shown in Figure 4 are coaxially disposed in a furnace 15 and the lower ends of the rod portion 24 and 23 and the second cylinder 31 and layer 22 are melted to flow downward and then drawn to a diameter reduced to a desired extent in the same way as shown in Figure 4. The optical transmission line as shown in Figure 6 and Figure 7 can thus be obtained in which the material for the second cylinder 31 is the same as that of the first cylinder 33.

As described above the method of producing the optical transmission line is in two steps which comprise pre-forming the core portion from the first cylinder and, thereafter, coaxially holding and heating the core portion and the second cylinder in the furnace as shown in Figure 10 and Figure 12. Alternatively, it is possible to eliminate the step for the construction of the core portion and carry out the first and the second steps simultaneously.

WHAT WE CLAIM IS:—

1. A method of producing an optical transmission line, comprising disposing a rod of a transparent medium coaxially within a hollow cylinder of a transparent medium having the same refractive index as said first medium and heating and drawing said rod and cylinder to reduce their diameters and form therefrom an integral fibre, said method including, before said heating and drawing step the step of forming, on the external surface of said rod or on the internal surface of said cylinder, a transparent layer having a refractive index higher than that of the medium of the rod or the cylinder.

2. A method as claimed in claim 1, wherein said rod comprises a solid rod having, within the said transparent medium thereof a core of a material having a higher

dielectric loss tangent than the medium of said rod.

3. A method as claimed in claim 2, including the step of forming said rod by providing a layer of said core material on the internal surface of a hollow cylinder of said transparent medium, and heating and drawing said hollow cylinder to reduce its diameter and to close the bore therein.

4. A method as claimed in claim 3, wherein the said transparent layer is formed on the external surface of said rod prior to the step of drawing the rod to close the aperture therein.

5. A method as claimed in claim 1, wherein the said rod comprises a hollow cylindrical rod and said method further includes, before said heating and drawing step, the step of providing on the internal surface of said rod a layer of a material having a higher dielectric loss tangent than the material of the rod, whereby during said heating and drawing step the aperture in the hollow rod is closed and the said internal layer forms a solid central core of the said fibre.

6. A method as claimed in any one of claims 2—5, wherein the medium of said central core is formed by adding thereto a small amount of a transition metal element having a high absorption for the wavelength to be transmitted by said transmission line.

7. A method as claimed in any one of the claims 1—6, wherein the or each said layer is initially deposited in fine powder form and is then sintered to effect vitrification thereof.

8. A method as claimed in any one of claims 1—6, wherein the or each said layer is deposited in a vitreous state in a single step.

9. A method of producing an optical transmission line, substantially as described herein with reference to Figures 1 to 4, Figures 5 to 8, Figures 9 and 10 or Figures 11 and 12 of the accompanying drawings.

10. An optical transmission line when produced by the method claimed in any one of claims 1—9.

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1427826 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG. 1

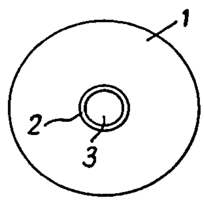


FIG. 2

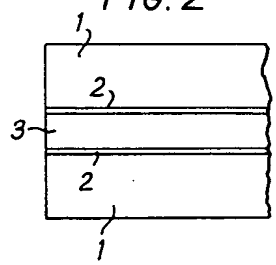


FIG. 3

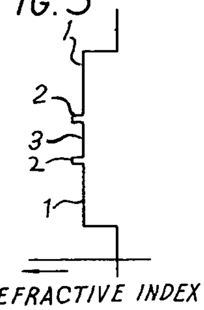
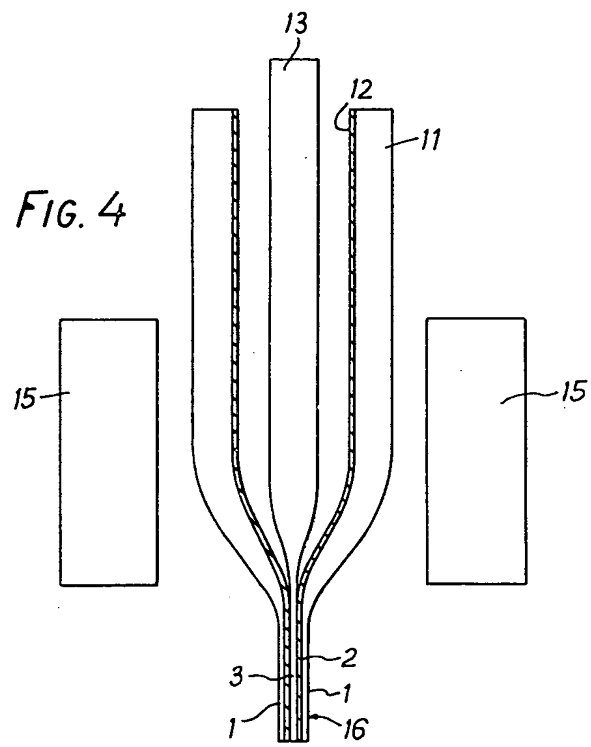


FIG. 4



1427826 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

FIG. 5

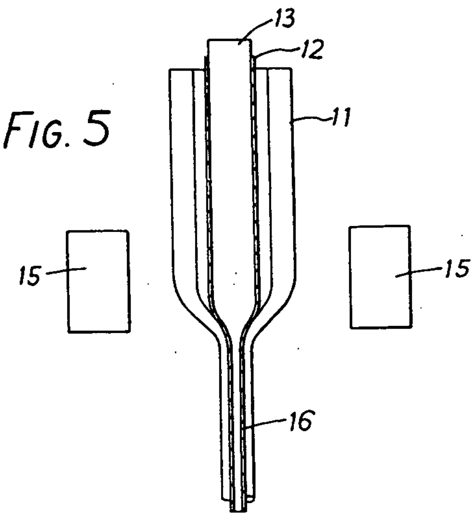


FIG. 6

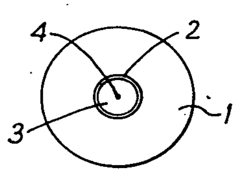


FIG. 7

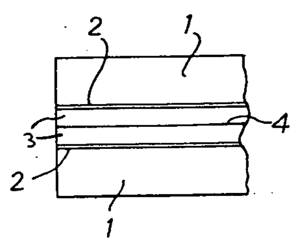


FIG. 8

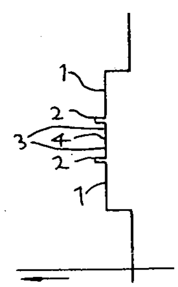


FIG. 9

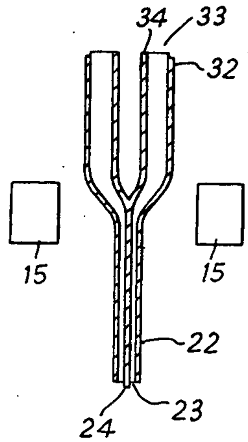


FIG. 10

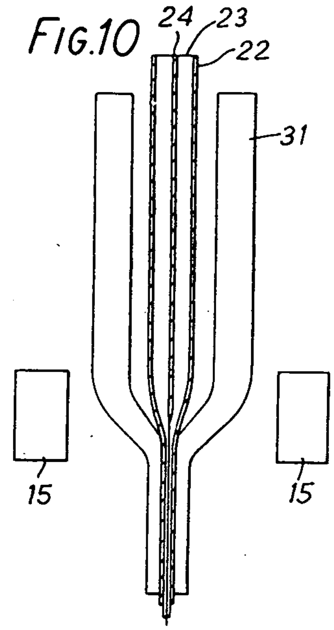


FIG. 11

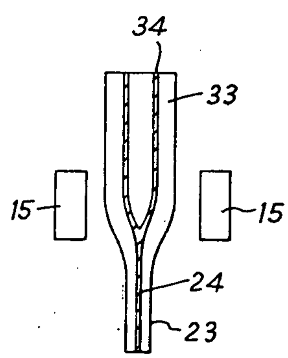


FIG. 12